

Advanced Reciprocating Engine Technology at the Oak Ridge National Laboratory (ORNL)

Presented By Ron Graves

**California Advanced Reciprocating
Internal Combustion Engine
Collaboration**

July 10, 2001

Presentation outline:

- **Base experimental capabilities/know-how**
- **Distinguishing capabilities/know-how**
- **Examples of projects (inc ARES project)**

Advanced Propulsion Technology Center is a comprehensive laboratory for internal combustion engines / powertrains

- Designated as a DOE National User Facility
- Can apply a number of unique or extraordinary diagnostic and analytical tools for engine/emission control R&D
- Conducts R&D from bench-scale to full system
 - Flow reactors for sensor and catalyst R&D
 - 5 dynamometer stands: 25-400+ horsepower
 - Emissions analysis with high resolution of time and species

Engine/Emissions projects at ORNL encompass multiple sponsors.....

- **DOE Office of Power Systems Technology**
- **DOE Office of Heavy Vehicle Technologies**
 - Fuels
 - Engines & Emission Controls
 - Systems
- **DOE Office of Advanced Automotive Technologies**
 - Fuels
 - Emission Control R&D
 - Systems
- **Army**

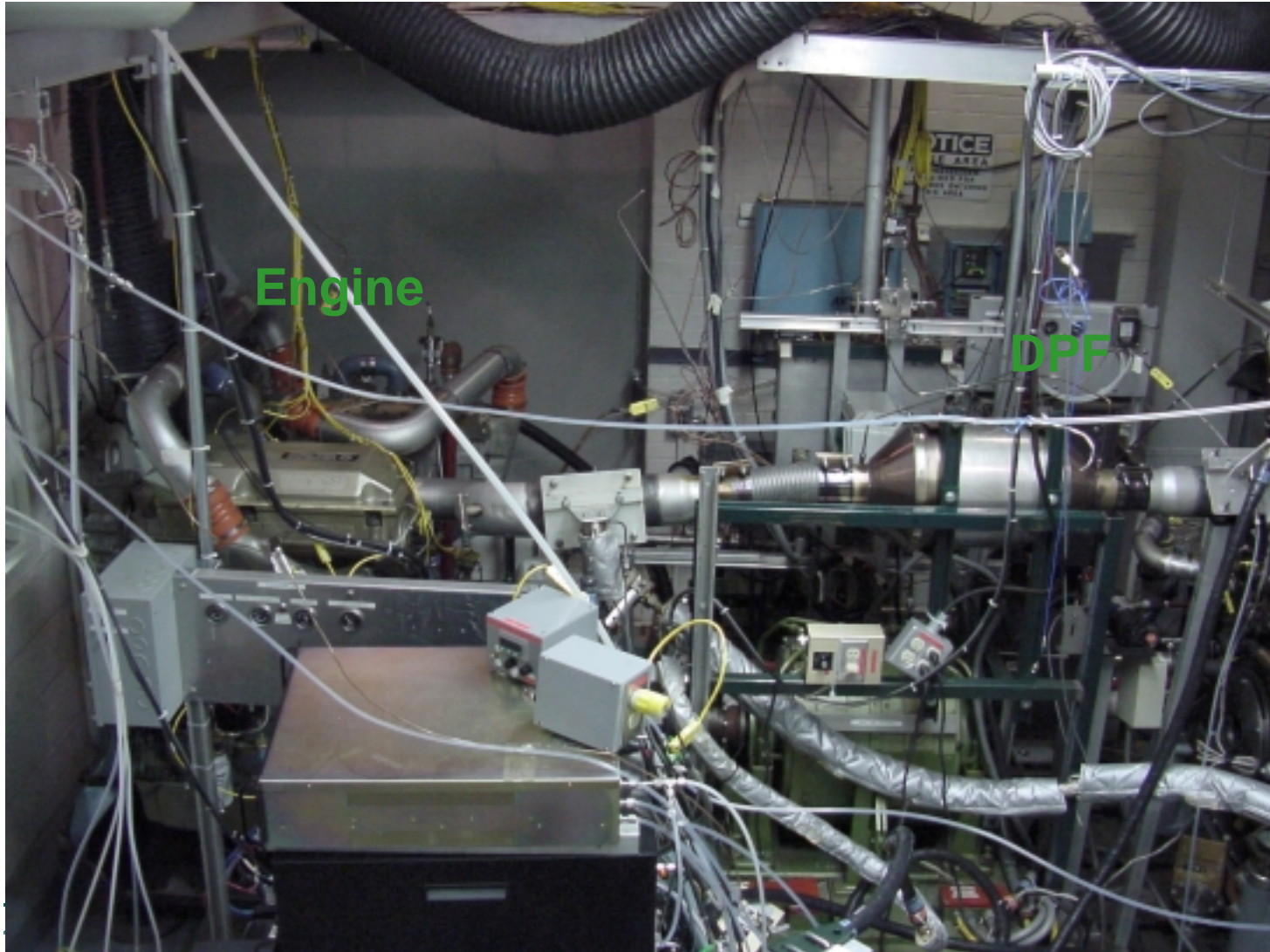
....and multiple partners

- **Eight CRADAs with engine and auto companies**
 - Cummins, Detroit Diesel, Ford, USCAR, International Engine Company
- **Informal collaborations with aftertreatment suppliers**
 - Members of Manufacturers of Emissions Controls Assoc. (MECA)

Basic tools for emissions research well-established

- **Five dynamometer stands ranging from 25-400 horsepower (2 motoring). Motoring to 600 hp by Dec 2001**
- **Bench flow reactor for catalyst and sensor characterization**
- **High-speed data acquisition**
- **Chassis dynamometer previously at U. Tennessee, now functional at NTRC**
- **Emissions measuring equipment for NO_x, CO, Hydrocarbons, particulates, including FTIR, Fast FID, Fast-NO_x**
- **Multiple methods for PM sizing, PM composition**

DDC Series 50 and DPF installed at ORNL, typical of four dyno cells



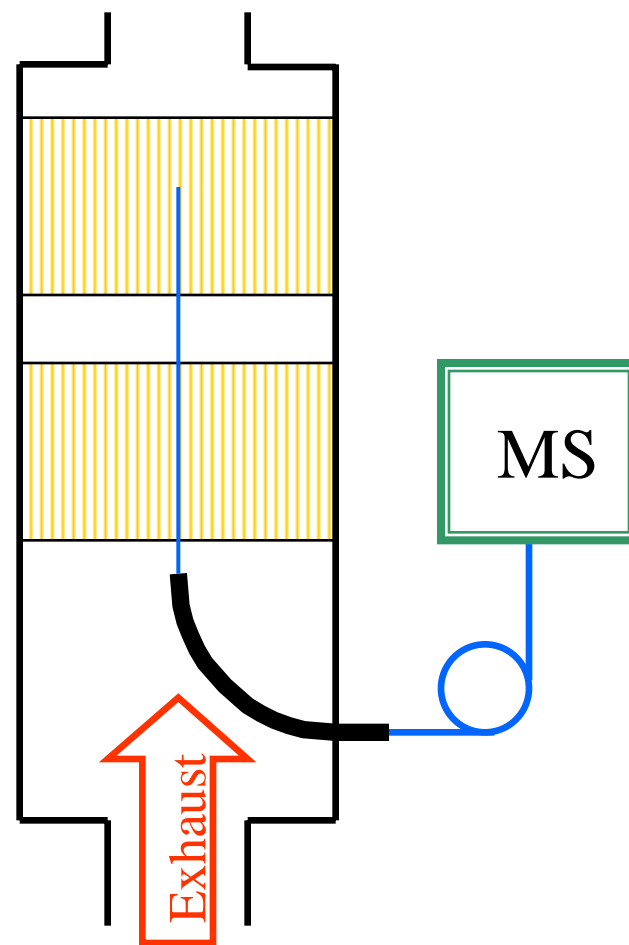
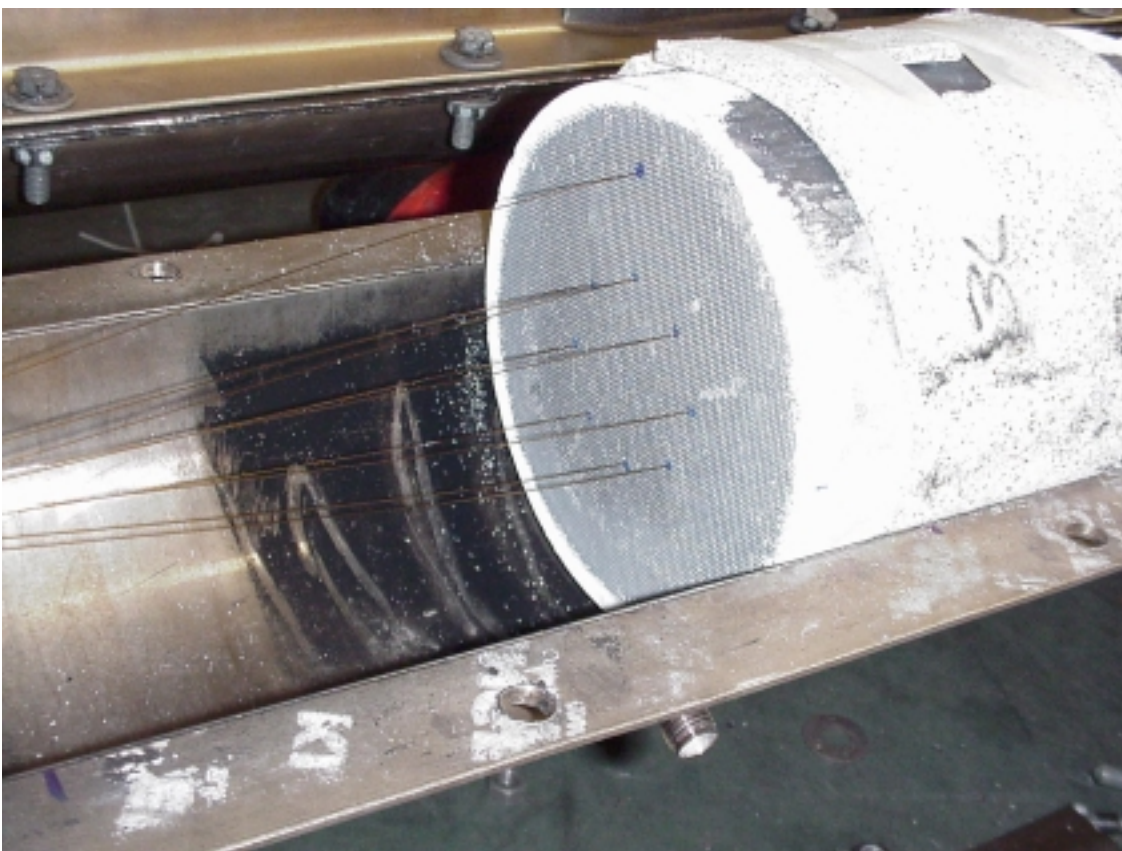
R&D staff “know-how”distinguished strengths

- **Emission measurement in general**
- **PM measurement/characterization**
- **Emission control engineering**
- **Exhaust speciation**
- **Vehicle-level chassis dyno experimentation**
- **Non-linear dynamics/real-time controls**
- **Electrical signature analysis**
- **Electrical machinery/power electronics**
- **Materials development and characterization (elsewhere at ORNL)**
- **Able to recognize and respond to industry needs**

Advanced research tools emphasize faster response and more sensitivity

- **Mobile, capillary inlet mass-spec**
- **UV absorption for ammonia and SO₂**
- **RTAMS - real time aerosol mass spec**
- **Diesel particle scatterometer**
- **Catalyst IR imaging**
- **Other optical techniques**
 - Phosphor thermography
 - LIF for oil films and deposits
 - other

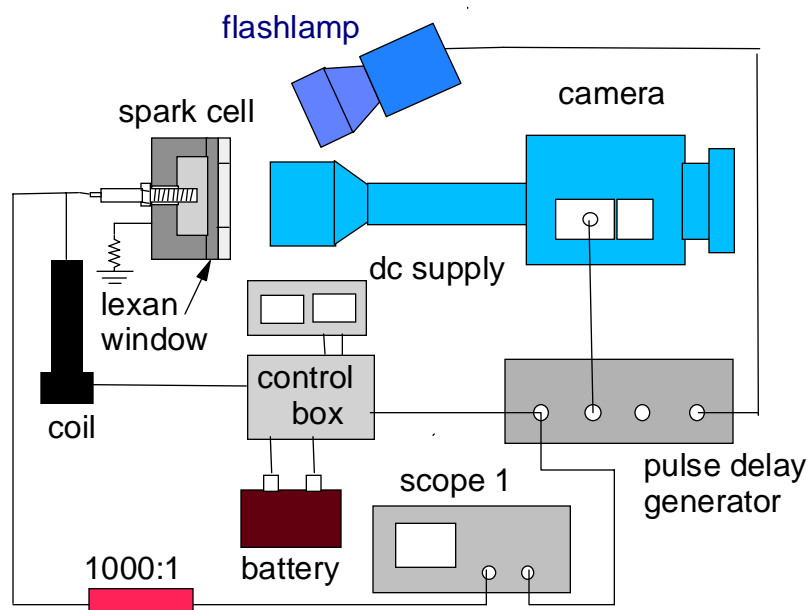
Spatially & temporally resolved species in functioning catalysts with capillary inlet mass spec



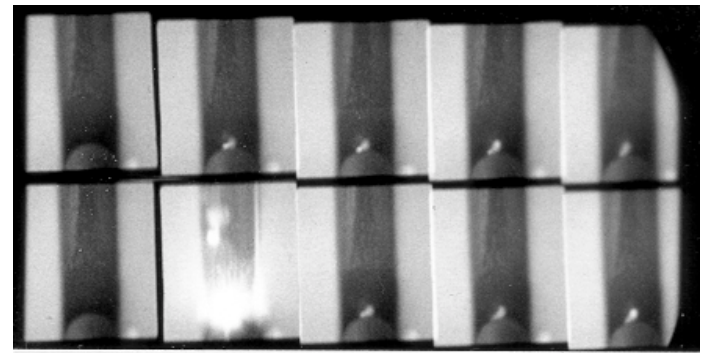
- Electronic valve switches SpaciMS input between sample locations

Measurement and modelling of arc dynamics, ORNL-Cummins CRADA

ORNL experimental apparatus applied to characterize breakdown event



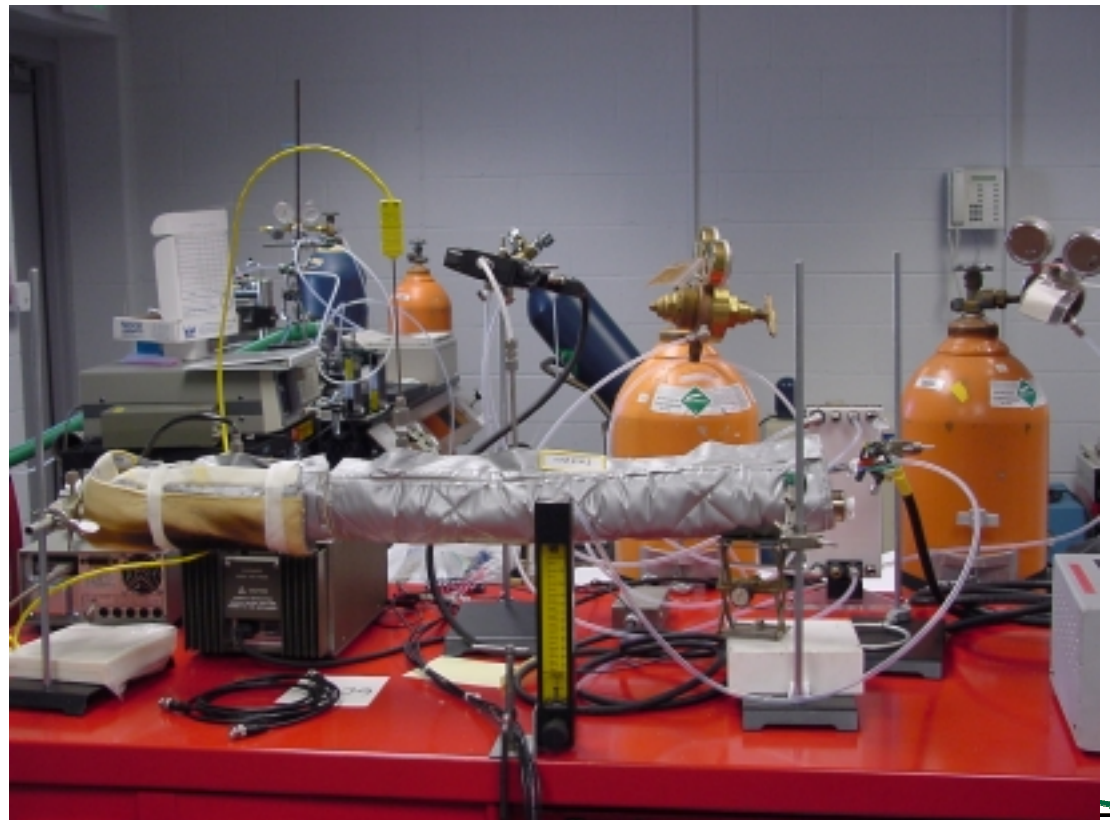
Fast framing photography (200,000 frames/sec) in a high-pressure spark cell shows arc formation, location, and speed. Each frame shows $5 \mu\text{s}$ for a total elapsed time of $50 \mu\text{s}$



Emerging NOx sensors characterized in CRADA between Ford & ORNL

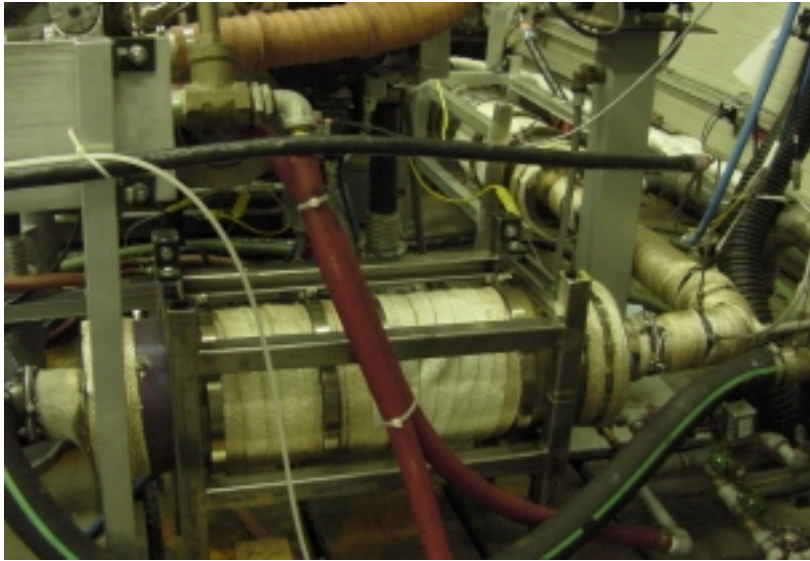
- **Sensor response times determined as function of temperature for NOx and oxygen in bench rig, up to 400C**
- **Steady state pumping current values determined for NO and oxygen.**
- **The current versus content curves were linear and corresponded well to values obtained by Ford**
- **Next effort is to measure sensor pumping currents under transient conditions**

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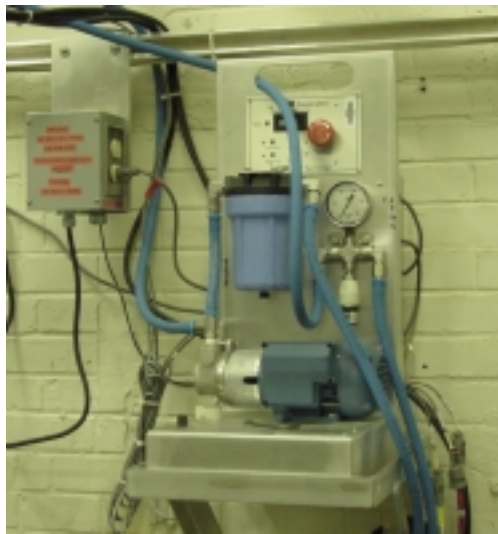
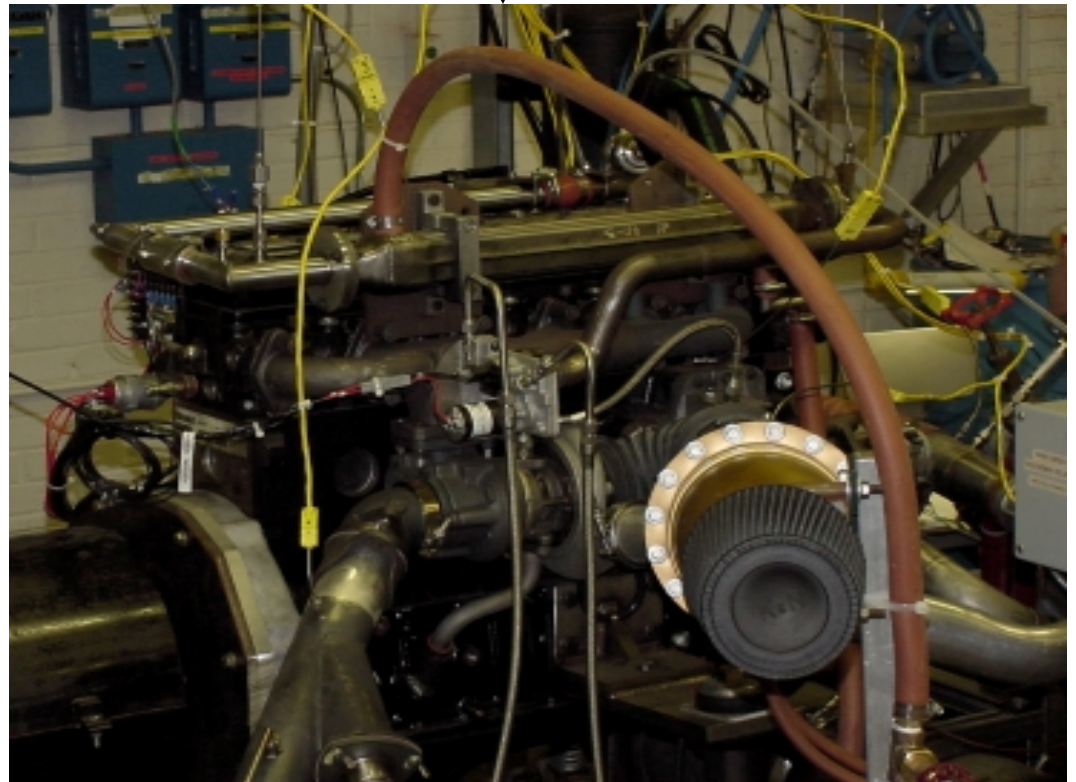
OF-BATTELLE

The “Zero” regulated emissions project at ORNL has integrated engine+aftertreatment+clean fuel



← CRT & SCR catalysts

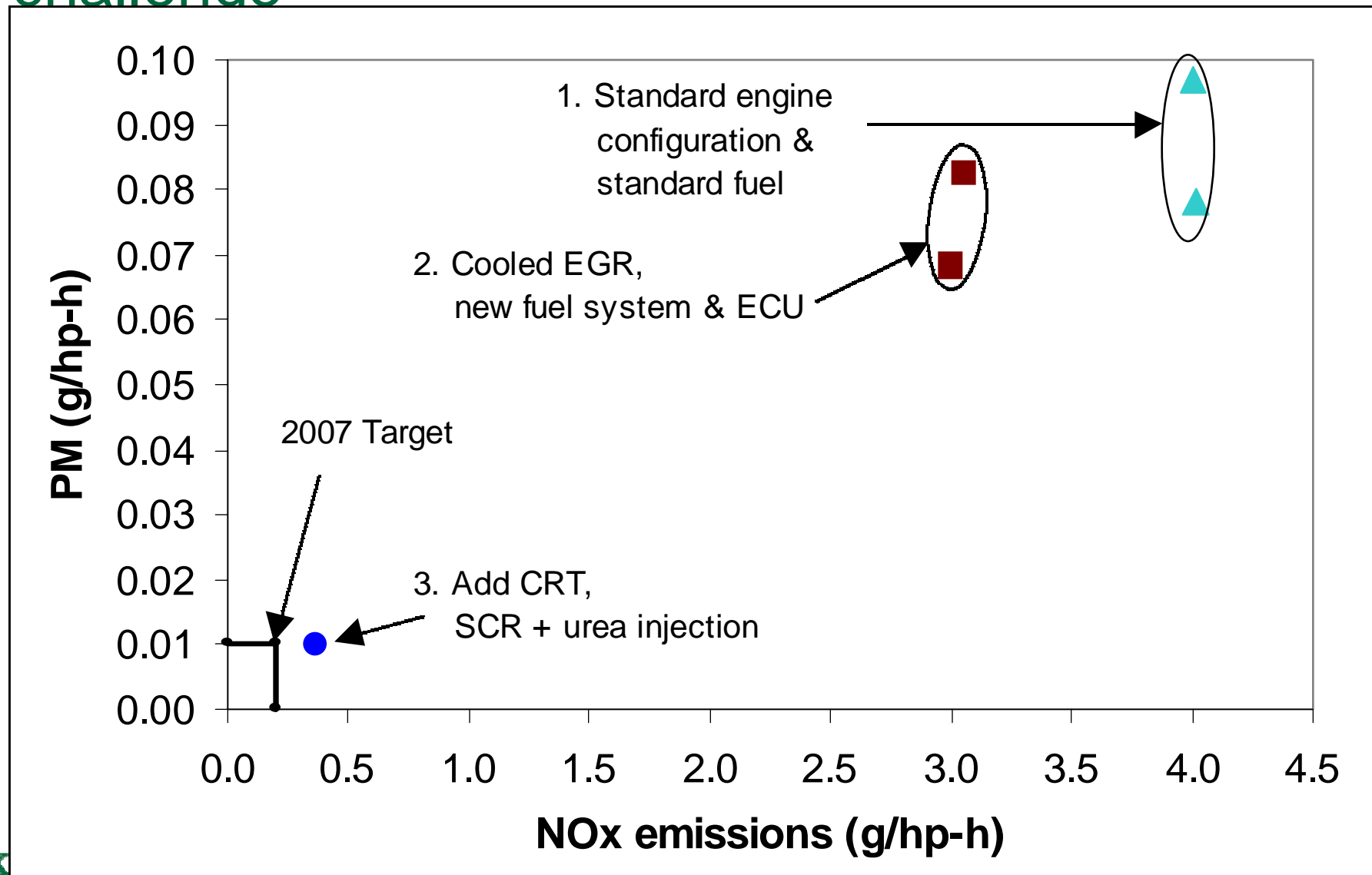
Cummins ISB engine with EGR



Urea
spray
system

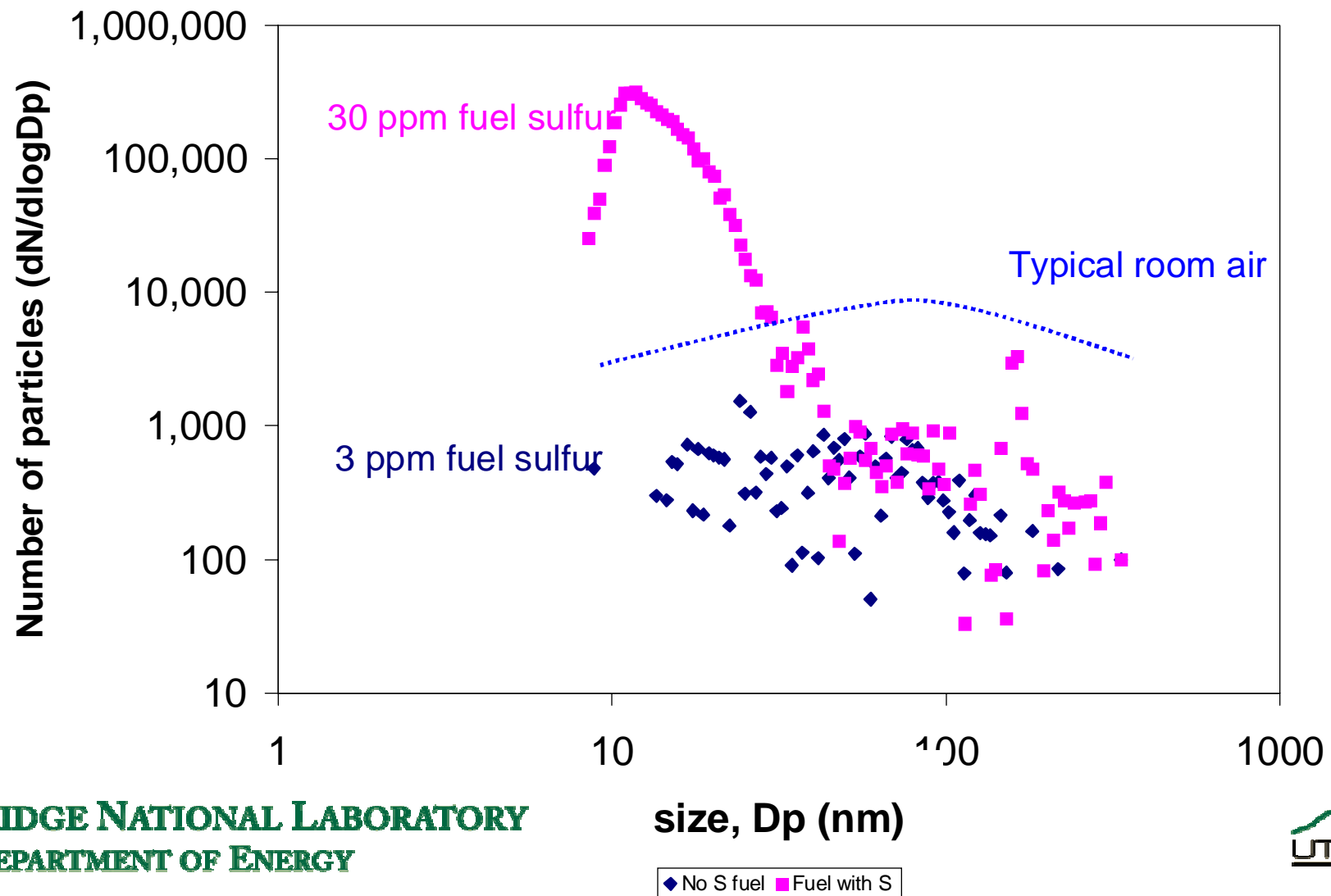


Early results show potential for major reductions in NOx and PM, yet highlight the daunting NOx challenge



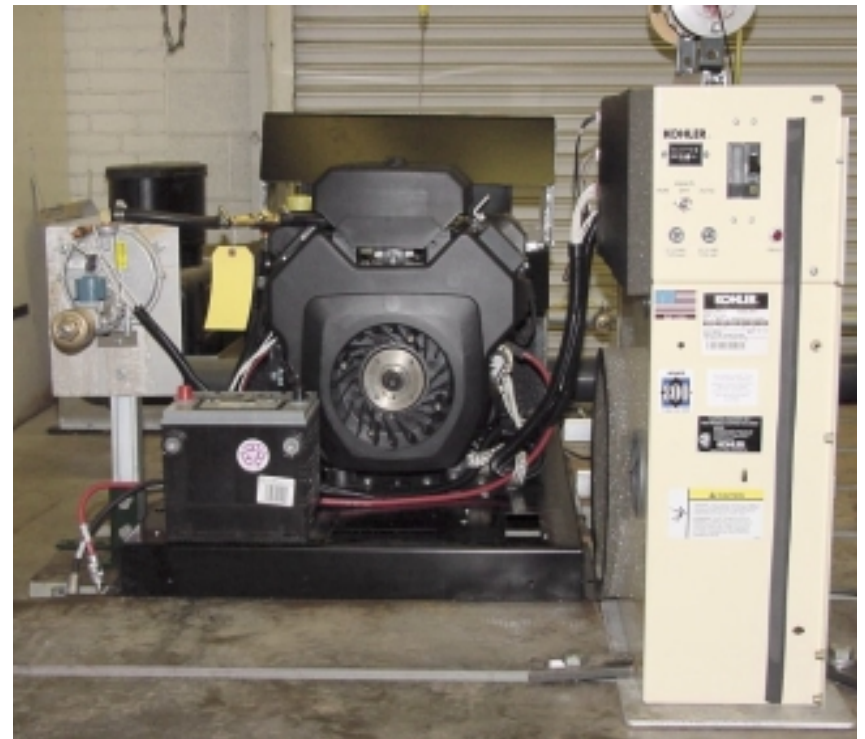
Fuel Sulfur isolated as cause of nanoparticles exiting CDPF

DDC Series 50, 2100 rpm, 100% load, sulfur-free lube (ORNL data)



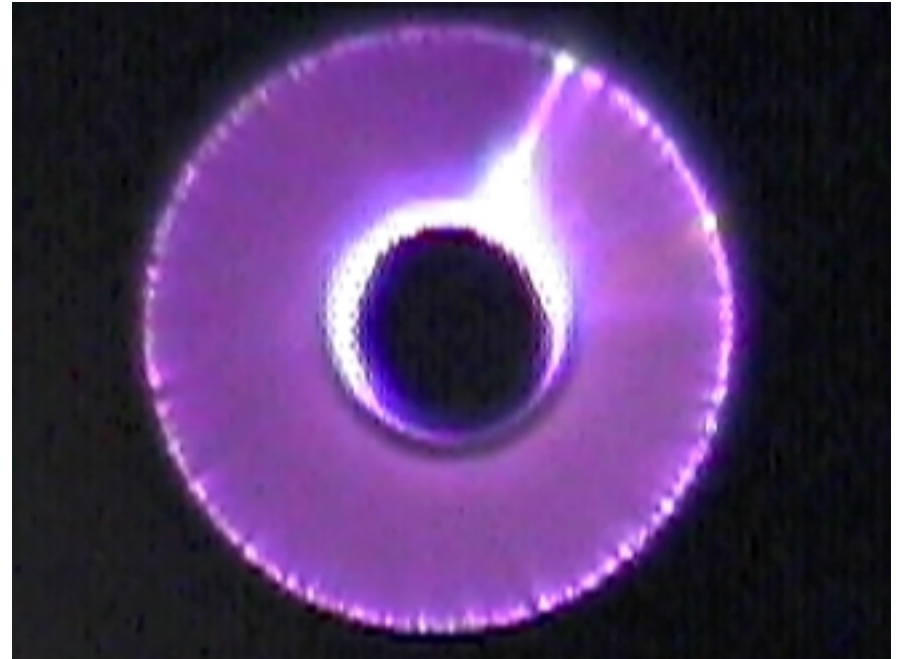
Ultra-Lean Burn Natural Gas Engine for DOE ARES Program

- **Integrate new technologies**
 - New rotating spark increases probability of ignition
 - H₂ addition for combustion stabilization extends lean limit
 - Nonlinear controls (future) - allows operation closer to lean burn limit
- **Demonstrate on existing system (9.5 kW Kohler NG generator set)**



Rotating Arc Spark Plug (RASP) being reduced to practice to aid lean limit

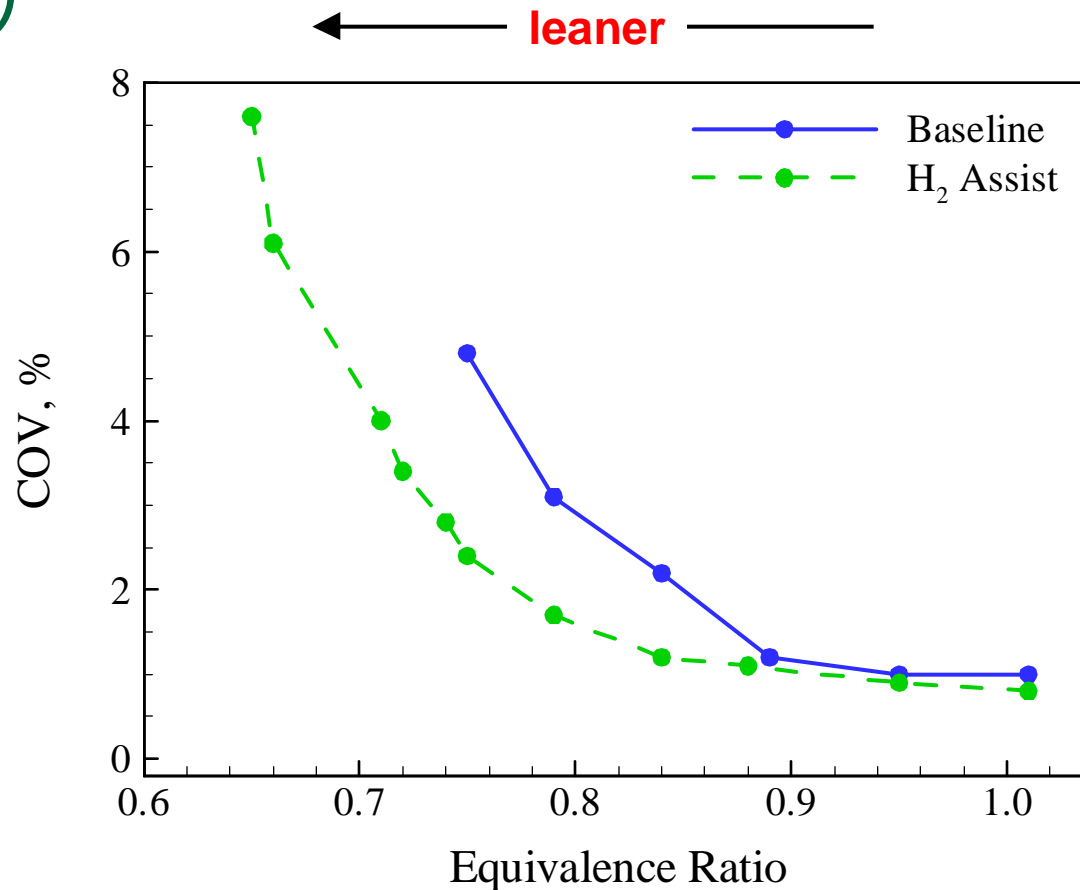
- Initially conceived with ORNL discretionary funds
- Product of team from plasma (Fusion) staff and R&D team on dielectrics
- Arc rotation and “blinking”



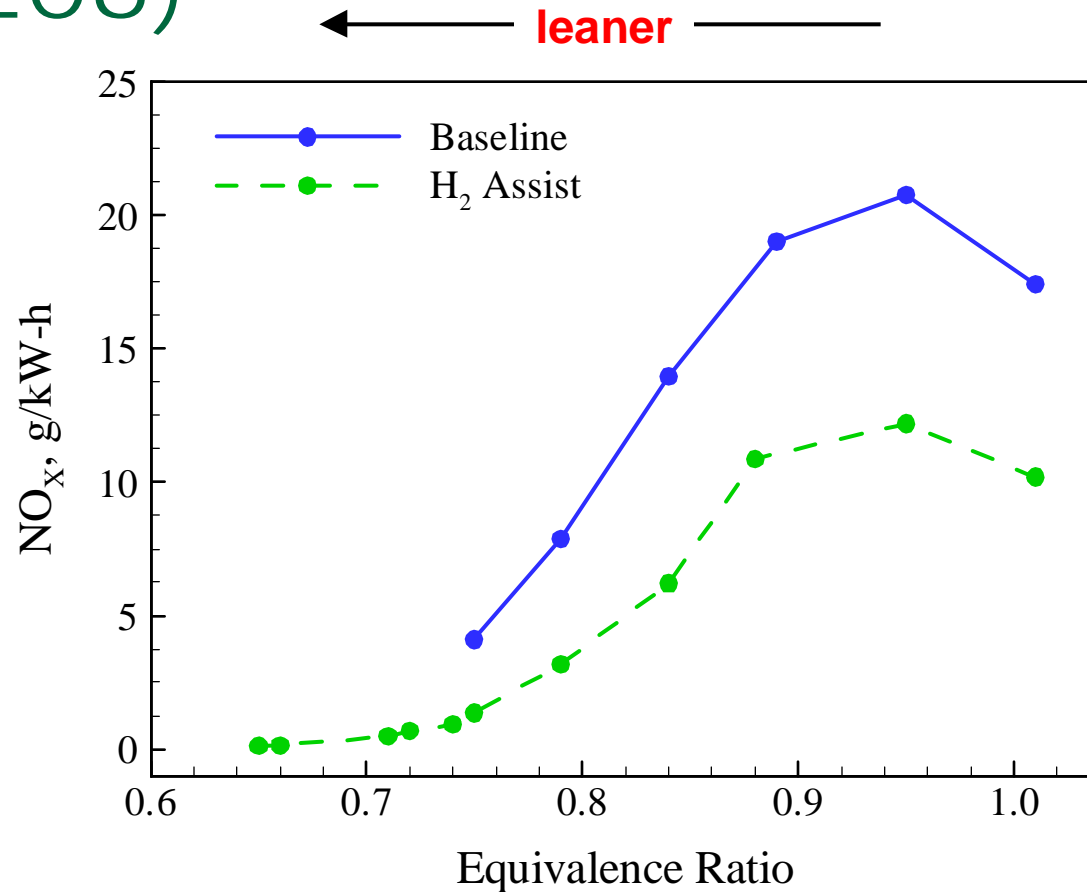
Why add reformatate gas?

- **Lean operation leads to combustion instability.**
- **H₂ has wide flammability limits and helps to initiate and sustain combustion under very lean conditions.**
- **Generation of reformatate gas by partial oxidation is proven technology and produces H₂, CO, and N₂ from CH₄.**
- **Integration of reformer into control system is feasible.**

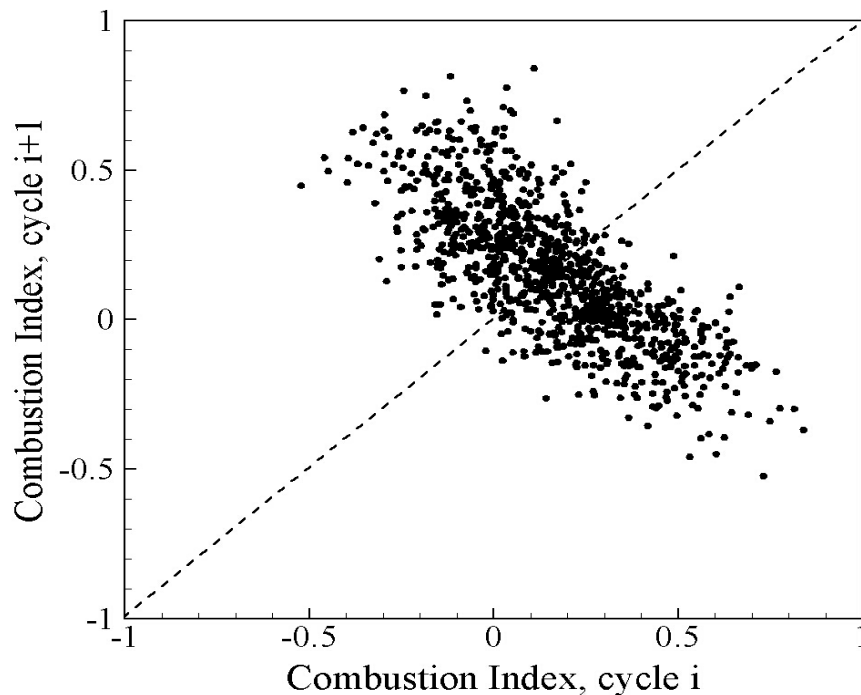
Reformate extends lean limit of stable operation (SAE 2000-01-2206)



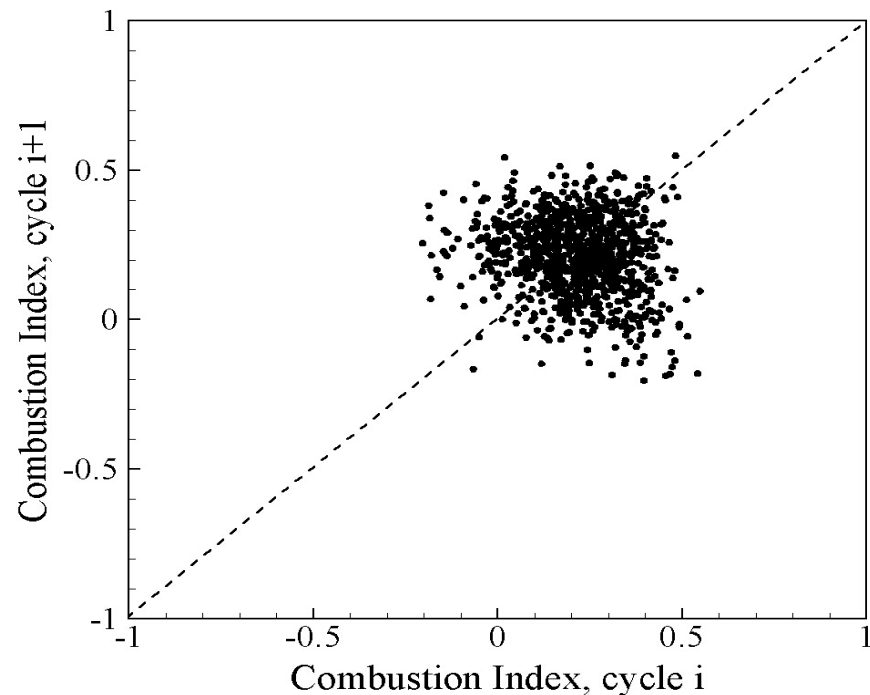
Addition of reformat gas reduces NO_x in gasoline engines (SAE 2000-01-2206)



Nonlinear control in an automobile has been demonstrated by ORNL and Ford Motor



Uncontrolled



Controlled

Thank you for inviting us to the
ARICE meeting